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REPORT ON THE ELIMINATION OF DETONATION WITH "AVIATION" AND "MOTOR" GASOLINE BY THE ADDITION OF XYLIDINE, ORTHO-TOLUIDINE, BENZOL, AND GENERAL MOTORS ANTI-KNOCK No. 1

(POWER PLANT SECTION REPORT)

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Prepared by Engineering Division, Air Service
McCook Field, Dayton, Ohio

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CERTIFICATE.—By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

INDEX.

REPORT ON THE ELIMINATION OF DETONATION WITH "AVIATION" AND "MOTOR" GASOLINE BY THE ADDITION OF XYLIDINE, ORTHO-TOLUIDINE, BENZOL, AND GENERAL MOTORS ANTI-KNOCK NO. 1.

OBJECT OF TEST.

The object of these tests was to investigate the effectiveness of various antiknock compounds in eliminating detonation with aviation and low test gasoline.

RESULTS OF TEST.

The following table shows the percentages of antiknock compounds required to eliminate detonation with aviation and low test gasoline with various compression ratios, as determined by this test:

Fuel.	Compression radio.	Engine.	Ortho-toluidine (per cent).	Xylidine (per cent).	Benzol (per cent).	General Motors Anti-knock No. 1.
Aviation gasoline.	6.7:1	Single-cylinder Liberty engine.	5.5	5.0	45.0	9.0
	5.4:1	Single and six cylinder Liberty engine.	2.25	1.75	18.0	3.0
	5.3:1	Hispano model "H".	2.25	....	22	....
Low test gasoline.	6.7:1	Single-cylinder Liberty engine.	[1] 10.0	[1] 9.5	[1] 60.0	[1] 16.0
	5.4:1	Single and six cylinder Liberty engine.	[1] 7.0 [2] 4.5	[1] 7.0	[1] 35.0	[1] 10.5
	5.3:1	Hispano model "H".	[2] 5.0	....	[2] 37.0	....

[1] Low test gasoline of specific gravity 0.744 at 15° C.
[2] Low test gasoline of specific gravity 0.730 at 15° C.

CONCLUSIONS.

Xylidine appears to be the most effective of the antiknock compounds tested, as regards amount required to eliminate detonation. The highest mean effective pressures were obtained using benzol as the antiknock agent with aviation gasoline.

METHOD OF TEST.

Place, McCook Field.

Date, August 7, 1920–February 15, 1921.

Test engineer, George M. Paulson.

The results of tests which have been conducted on the single-cylinder Liberty engine to determine the effect of various antiknock mixtures under full-throttle operation are covered in a preliminary Engineering Division Report, Serial Number 1711. Since full-throttle operation on the single-cylinder engine gave much higher indicated mean effective pressures than are obtained in multicylinder engines, it was desired to investigate the effectiveness of these antiknock mixtures with the engine throttled to give indicated pressures corresponding to those obtained in service engines. It was also desired to determine the effectiveness of these antiknock mixtures with standard service type multicylinder engines. This test was undertaken to provide such data.

The antiknock substances used were xylidine, ortho-toluidine, General Motors Anti-Knock No. 1 and "Commercial" 90 per cent benzol. Xylidine and ortho-toluidine are coal-tar products homologous to aniline and belonging to the amine series. General Motors Anti-Knock No. 1 consists of homologues of aniline belonging to the amine series, mixed with a small proportion of benzol to insure miscibility with gasoline. Commercial xylidine purchased from the Cincinnati Chemical Works, Cincinnati, Ohio, was used on this test. The other fuels used were as follows:

Ortho-toluidine:
- 50 per cent ortho-toluidine.
- 50 per cent aniline.

Anti-Knock No. 1:
- 70 per cent aromatic amines.
- 30 per cent "Commercial" 90 per cent benzol.

Trioxyalene (see distillation curve figure 1):
- 80 per cent low test gasoline.
- 20 per cent sulphuric ether.

Benzol, "Commercial" 90 per cent (see distillation curve figure 1).

"Aviation" and "Low Test" (Motor) gasolines, War Department Specifications 2–40 and 2–41 (see distillation curves, figure 1).

The low test gasoline of specific gravity 0.744 is about as low as could be accepted under the above specifications.

These tests were conducted on a single-cylinder Liberty engine with compression ratios of 5.4:1 and 6.7:1 and on standard Liberty six-cylinder and 300-horsepower Hispano-Suiza engines. Runs were made with mixtures of aviation and low-test gasolines with ortho-toluidine, xylidine, benzol, and General Motors Anti-Knock No. 1. A few runs with trioxyalene mixtures were also made. During some of the runs 1 per cent to 3 per cent of benzol was added to the ortho-toluidine mixtures to obtain complete miscibility. All mixtures were proportioned by volume.

The Liberty cylinder used had two extra spark plug bosses under the valves. It was mounted on a universal crank case (described in Air Service Information Circular Vol. I, No. 47), coupled to an electric dynamometer, the reaction of which was weighed on a Toledo springless scale. Two standard A. C. plugs were used in the positions under the valves for all the runs except a few with the Midgley indicator. To obtain the indicator cards showing pronounced detonation, plugs were fitted in one of the regular Liberty plug positions and in the position under the exhaust valve. A Zenith carburetor with fixed setting and magneto ignition with a maximum possible advance of 45° were used. The fuel consumption was measured by means of a 2,000 cubic centimeter glass tube graduated in divisions of 10 cubic centimeters, which was used to supply the fuel. The revolutions of the engine were obtained from a revolution counter connected direct to the engine, and were held constant at approximately

1,700 revolutions per minute for all the runs. During each run, readings of the engine revolutions, the brake load, water temperatures in and out, carburetor air temperatures and spark advance were taken. Data tables incorporating the results of these runs are included on pages 4 to 8.

The following runs were made:

RUNS WITH SINGLE-CYLINDER LIBERTY ENGINE 6.7 : 1 COMPRESSION RATIO.

Run No. 1, engine throttled,[1] using aviation and low test gasoline.

Run No. 2, engine throttled, using aviation and low test gasoline with ortho-toluidine, xylidine, and benzol.

Run No. 3, full-throttle operation, using mixtures of trioxyalene and aviation gasoline with ortho-toluidine, xylidine, and benzol.

Run No. 10, engine throttled, using aviation and low test gasoline with General Motors Anti-Knock No. 1.

RUNS WITH SINGLE-CYLINDER LIBERTY ENGINE, 5.4 : 1 COMPRESSION RATIO.

Run No. 6 full-throttle and throttled operation, with aviation gasoline mixtures with ortho-toluidine and xylidine.

Run No. 7, engine throttled, using low test gasoline mixtures with ortho-toluidine and xylidine.

Run No. 8, engine throttled, using aviation and low test gasoline with benzol.

Run No. 9, engine throttled, using aviation and low test gasoline with General Motors Anti-Knock No. 1.

RUNS WITH STANDARD MULTICYLINDER ENGINES.

Run No. 4, Liberty six-cylinder engine, 5.4 : 1 compression ratio, using aviation and low test gasoline with ortho-toluidine and benzol.

Run No. 5, 300-horsepower Hispano-Suiza engine, 5.3 : 1 compression ratio, using aviation and low test gasoline with ortho-toluidine.

During all of the single-cylinder runs, as little time as possible was lost between runs of different mixtures which lasted from two to three minutes, the mixtures being changed without stopping the engine. The "throttled" runs were made with the throttle set to give the same indicated mean effective pressures as would be obtained in multicylinder service engines of approximately the same compression ratio. These indicated mean effective pressures were computed from the brake mean effective pressures and mechanical efficiencies obtained on tests of several multicylinder engines, and were 146 pounds per square inch for 6.7 : 1 compression ratio, and 134 pounds per square inch for 5.4 : 1 compression ratio. The multicylinder engine tests with 6.7 : 1 compression ratio on which these pressures are based, were conducted with a 50 per cent benzol and aviation gasoline mixture as fuel. The corresponding brake loads for the single-cylinder runs were computed, using 80 per cent as the mechanical efficiency of the Liberty single-cylinder engine. (See Mechanical Efficiency Determination in Air Service Information Circular, Vol. II, No. 199.)

The Liberty six-cylinder and Hispano-Suiza 300-horsepower engines used had normal compression ratios of 5.4 : 1 and 5.3 : 1, respectively, and were run on a Sprague electric dynamometer. Particular attention was given to the spark adjustment, which was arranged so that a maximum advance of about 42° could be obtained. Two fuel tanks were used, one for a fixed fuel mixture which would not detonate, and the other for the mixture to be tested. These tanks were connected so that the flow could be switched rapidly from one to the other. The water temperatures were kept as nearly constant as possible at 170° F. in the Liberty engine and 150° F. in the Hispano-Suiza engine. The oil temperatures were also held as nearly constant as possible.

Early in the tests it was found that the spark setting had a very marked effect on detonation, and it was therefore found necessary to vary the spark advance for each fuel in order to determine whether or not detonation had been eliminated with the spark set at the point for maximum power. To do this, it was necessary to distinguish between the power drop due to excessive spark advance and that due to detonation. It was assumed that detonation was completely eliminated if, as the spark was advanced, a drop in power was obtained before detonation could be heard. With each mixture, as the spark was advanced, the amount of advance, in degrees, was noted for best power, for the point at which detonation was heard, and the point at which a drop in power was obtained. The mixtures recommended are generally those at which a drop in power due to spark advance could be obtained before severe detonation set in.

A Midgley indicator was set up on the single-cylinder Liberty engine with 6.7:1 compression ratio in order to check the results of the runs and to learn as much as possible about the combustion of the different fuel mixtures and the cylinder pressures obtained. The Midgley indicator shown in figures 3, 4, and 5 consists of three main parts—a pressure element, an indicator unit, and a timing device. The pressure element screws into a spark plug boss in the cylinder, and by means of a piston exposed to the cylinder pressure rocks a small concave mirror about a horizontal axis. This concave mirror catches a beam of light from a point source in the indicator unit and reflects it back in the indicator unit to an octagonal prism, the faces of which are mirrors, and which is synchronized to revolve about a vertical axis at one-eighth of engine speed. The revolving mirrors catch the beam of light from the pressure element mirror and reflect it to the ground glass shown in position in figure 5, on which the beam traces a pressure-time card, the beam transversing the ground glass from left to right once for each revolution of the engine. The timing device shown in the foreground of figure 4 is driven at engine speed, and consists of a distributor, cam, and solenoid. The distributor synchronizes the motor in the indicator unit driving the revolving mirrors with the engine revolutions. The solenoid in conjunction with the cam serves to operate a shutter at the light source and to intensify the light by increased voltage for two revolutions of the engine.

The pressure-time cards were photographed by means of a special film adapter constructed for the tests. The indicator unit and film adapter are shown in figure 3. By pressing a button operating the solenoid and cam an exposure of the film could be made for two revolutions or a complete cycle of engine events.

[1] In this report the word "throttled" indicates that the engine was throttled to give indicated M. E. P.'s equal to those obtained in multicylinder engines as explained above, with ortho-toluidine.

ANALYSIS.

Throughout the test xylidine was found to be the most effective antiknock substance of those tested. While the ortho-toluidine mixture was found to be almost as effective, it did not mix thoroughly with gasoline at low temperatures without a slight addition of benzol. The General Motors Anti-Knock No. 1 gave no trouble in mixing, but to eliminate detonation was required in larger percentages than either xylidine or ortho-toluidine. In all cases the best power was obtained with the engine detonating slightly. The highest mean effective pressures were obtained with mixtures of benzol and aviation gasoline. Almost as high mean effective pressures were obtained, however, with any of the antidetonating compounds mixed in the recommended proportions. The detonation could be made more severe or diminished by advancing or retarding the spark from the best power position, as is shown in some of the indicator cards. The results of the dynamometer runs are shown in the tables of date, pages 4 to 8.

In using the Midgley indicator it was desired to obtain pressure-time cards showing the effect on detonation of variations in the percentages of antiknock mixtures. A compression ratio of 6.7 : 1 was used, and all cards were taken at 1,700 revolutions per minute. In order to be sure that a card representative of average conditions in the cylinder was obtained, three exposures for a complete cycle were made on each film. Due to the double surfaces on one of the mirrors in the indicator, for each exposure one heavy and one light diagram were obtained. The upper diagram (see fig. 2) shows the occurrence of cycle events on one of the benzol cards (see fig. 6). Inertia of some of the indicator parts may be responsible for some of the waves obtained in the indicator diagrams, but the smooth waves due to this cause are easily distinguished from the sharp irregularities due to detonation.

The cards showing best the effect of variations in antiknock percentages and spark advance were obtained under full-throttle conditions and are shown in figures 7, 8, 9, 10, and 11. The slight amount of detonation shown by the sharp irregularities of the expansion lines in figures 7 and 10 is not sufficient to reduce the power delivery of the engine. Detonation such as is shown in figures 8, 11, 12, and 13 is heard as violent "pinking," and generally after a few minutes' running develops into preignition. The most violent detonation of any of the cards was obtained with trioxyalene, at part throttle, figure 13, and was due to the ether content of the fuel. This fuel, compared with other fuels, would allow very little spark advance without detonating violently, giving best power with about 25° advance. Figures 14, 15, 16, and 17 were taken with the throttle and spark set for best power without detonation, and show how the possible brake mean effective pressures with detonation eliminated vary with varying percentages of antiknock. Figure 18 was obtained with a mixture of low-test gasoline and Anti-Knock No. 1, and shows almost as good power results as were obtained from any other mixtures.

It was found that spark-plug positions considerably affected the cards obtained. When using the two plugs under the valves, preignition was obtained apparently without any signs of passing through a stage of detonation, but only with full throttle. As soon as either one of the standard Liberty plug positions was used, detonation could readily be obtained, with less than full throttle. The effect upon flame propagation of using one or two plugs is shown in figures 20 and 21. In both figures the brake mean effective pressure and revolutions per minute are the same, the spark being advanced sufficiently with the one plug to bring the power up to that obtained with two plugs. It should be noted that the rise in pressure is slower with one plug than with two. Figure 19 shows several exposures taken at the instant that preignition became so violent that the engine quickly decelerated from a speed of 1,700 revolutions per minute to less than 1,000 revolutions per minute. The effect of preignition was watched on several occasions, using the ground glass, and it was seen that as preignition developed the "burn" or line of pressure rise of the indicator card advanced rapidly relative to the engine top dead center, until the area on one side of the dead center of the card was almost equal to that on the other side, at which point the pounding of the engine became very severe and the engine was quickly brought to a stop. This card and all other cards obtained show maximum pressures very little higher than the maximum pressures obtained on the cards taken under the best power conditions. Even with the most pronounced detonation and preignition the maximum pressures seem to be about the same as those obtained with best power conditions.

The indicator was carefully calibrated with a Crosby pressure gauge calibrator. A pressure-volume card shown in figure 2 was constructed from one of the best power pressure-time cards obtained with 90 per cent benzol as fuel, figure 6, and the indicated mean effective pressure was obtained by means of a planimeter. The upper dead center on this card was located by taking a card at normal speed of the engine with the spark cut out while the exposure was made so that the curve obtained was of the compression and expansion of the charge without combustion, the dead center being approximately the mid point of the peak of the curve. A very close check of the indicated mean effective pressure with benzol figured from power and friction runs was obtained in this manner. The highest brake mean effective pressure obtained during the tests was 150.4 pounds per square inch, obtained with a mixture of 70 per cent benzol and aviation gasoline, during a run taking indicator cards. Taking the mechanical efficiency of the single cylinder on the universal engine as 80 per cent (as determined in single-cylinder tests), the indicated mean effective pressure obtained on this card would be 188 pounds per square inch. Assuming that this indicated mean effective pressure could be obtained in a multicylinder engine having a mechanical efficiency of 90 per cent, a brake mean effective pressure of well over 160 pounds per square inch would be possible.

In conclusion, it is believed that the percentages of the various antiknock compounds as determined by these tests are sufficiently liberal so that no trouble from detonation would be obtained in service engines using these percentages with normal spark settings. The possibilities of obtaining unusually high mean effective pressures by means of high compression and antidetonating compounds are worthy of further study.

RUN NO. 1.

Single cylinder Liberty engine—6.7:1 compression ratio—Throttle set to give 146 pounds per square inch indicated mean effective pressure with 50 per cent benzol mixture[1]*—Aviation and low test gasoline mixtures with ortho-toluidine.*

Per cent ortho-toluidine.	Revolutions per minute.	Brake load (pounds).	B. H. P.	Corrected—		Carburetor air temperature (° F.).	Spark setting (degrees).		
				B. M. E. P. (pounds per square inch).	I. M. E. P. (pounds per square inch).		Best power.	Detonation.	Power drop.
Aviation gasoline mixtures.									
4.0	1,690	79.50	33.6	116.8	146.0	56	28	36	38
4.5	1,700	79.75	33.9	117.2	146.5	54	28	36	40
5.0	1,700	79.25	33.69	116.5	145.6	53	28	40	38
5.5	1,700	78.50	33.36	115.4	144.2	53	28	40	40
Low test gasoline mixtures.									
1.5* 7.0	1,704	73.75	31.41	108.4	135.5	51	28	32	32
2.0* 7.5	1,720	74.00	31.82	108.7	135.9	52	28	32	36
2.0* 8.0	1,690	73.62	31.11	108.2	135.3	52	28	32	36
2.5* 9.0	1,710	75.50	32.28	110.9	138.7	57	28	32	36
3.0* 10.0	1,690	76.73	32.43	112.8	141.0	62	28	40	38

* Per cent benzol added to obtain miscibility. Barometer, 29.15 in. Hg.

[1] Multicylinder engine tests on which throttle settings for indicated mean effective pressures are based, were run with 50 per cent benzol mixture as fuel.

Carburetor settings for all single-cylinder runs:
Choke, 40 mm.
Main jet, 25.1 pt. per hr.
Comp. jet, 33.8 pt. per hr.

RUN NO. 2.

Single-cylinder Liberty engine—6.7:1 compression ratio—Throttle set to give 146 pounds per square inch indicated mean effective pressure with 50 per cent benzol mixture[1]*—Aviation and low test gasoline mixtures with (R) ortho-toluidine (X) xylidine and (B) benzol.*

Fuel mixture (per cent).	Revolutions per minute.	Brake load (pounds).	B. H. P.	Corrected—		Carburetor air temperature (° F.).	Spark setting (degrees).		
				B. M. E. P. (pounds per square inch).	I. M. E. P. (pounds per square inch.)		Best power.	Detonation.	Power drop.
Aviation gasoline mixtures. Barometer 29.13 in. Hg.									
1.0* 5.0 R	1,700	78.0	33.15	114.7	143.4	54	28	32	36
1.0* 5.5 R	1,700	79.0	33.57	116.2	145.2	53	32	36	36
4.0 X	1,700	78.12	33.20	114.9	143.6	56	28	32	40
4.5 X	1,700	79.50	33.79	116.9	146.1	56	28	32	40
5.0 X	1,690	79.75	33.70	117.3	146.6	54	32	36	36
5.5 X	1,706	79.75	34.02	117.3	146.6	56	32	37	36
Low test gasoline mixtures.									
9.0 X	1,710	77.00	32.92	113.2	141.5	58	32	36	40
9.5 X	1,700	77.75	33.04	114.3	142.9	59	32	37	36
Barometer changed to 29.05 in. Hg.									
10.0 X	1,680	74.50	31.29	109.8	137.3	65	32	40	36
Aviation gasoline mixtures.									
40.0 B	1,700	78.50	33.36	115.8	144.8	63	28	36	36
45.0 B	1,690	80.00	33.80	117.9	147.4	64	28	40	36
Low test gasoline mixtures.									
55.0 B	1,700	79.50	33.79	117.2	146.5	64	32	36	36
60.0 B	1,690	79.75	33.70	117.6	147.0	64	32	40	36

* Per cent benzol added to obtain miscibility.

[1] Multicylinder engine tests on which throttle settings for indicated mean effective pressures are based, were run with 50 per cent benzol mixture as fuel.

RUN NO. 3.

Single-cylinder Liberty engine—6.7 : 1 compression ratio—Various fuel mixtures, full-throttle operation—(T) Tri-oxylene, (R) ortho-toluidine, (X) xylidine, (B) benzol, (AG) aviation gasoline.

Fuel mixture (per cent).	Revolutions per minute.	Brake load (pounds).	B. H. P.	Corrected— B. M. E. P. (pounds per square inch).	Corrected— I. M. E. P. (pounds per square inch).	Carburetor air temperature (° F.).	Spark setting (degrees). Best power.	Spark setting (degrees). Detonation.	Spark setting (degrees). Power drop.
Barometer 28.90 in. Hg.									
100 T	1,690	74.0	31.27	109.7	137.1	61	14	24	24
100 T	1,770	76.5	33.85	113.4	141.8	63	14	24	24
3 R, 95 T	1,680	99.0	41.58	146.8	183.5	57	32	40	36
Barometer changed to 28.95 in. Hg.									
50 AG, 50 B	1,680	97.25	40.85	143.9	179.9	54	32	....	....
95 T, 5 X	1,680	98.00	41.16	145.0	181.2	54	28	....	....
93.5 T, 6.5 X	1,670	98.00	40.91	145.0	181.2	53	32	....	....
50 T, 50 B	1,630	98.75	41.72	146.1	182.6	52	32	....	....
40 T, 60 B	1,680	99.75	41.90	147.6	184.5	52	32	....	....

RUN NO. 4.

Liberty six-cylinder engine—Compression ratio, 5.4 : 1—Aviation and low test gasoline mixtures with (R) ortho-toluidine and (B) benzol.

Per cent dope.	Revolutions per minute.	Actual— Brake load (pounds).	Actual— B. H. P.	Corrected— H. P.	Corrected— B. M. E. P. (pounds per square inch).	Water temperature (°F.): In.	Water temperature (°F.): Out.	Carburetor air temperature (°F.).	Spark setting (degrees). Best power.	Spark setting (degrees). Detonation.	Spark setting (degrees). Power drop.
Aviation gasoline mixtures. Barometer, 28.85 in. Hg.											
*	1,720	368.5	211.2	219.1	122.4	150	162	63	29	....	....
3.5 R	1,730	360.0	207.6	215.3	119.5	147	180	63	28	34	31
3.0 R	1,710	364.5	207.7	215.4	121.1	140	172	63	28	34	31
2.5 R	1,710	363.5	207.1	214.8	120.8	159	170	63	28	34	31
*	1,710	364.5	207.7	215.4	121.1	166	175	63	28	....	....
Barometer changed to 29.05 in. Hg.											
*	1,720	372.5	213.6	220.0	122.8	151	165	49	29	....	....
2.0 R	1,700	369.0	209.1	215.4	121.7	160	173	49	28	30	32
1.5 R	1,700	363.0	205.7	211.9	119.7	166	178	47	26	26	31
2.0 R	1,710	368.0	209.7	216.0	121.4	170	179	47	27	31	35
Aviation gasoline mixtures.											
*	1,710	369.0	210.3	216.4	121.6	179	170	52	27	....	....
4 R	1,720	357.0	204.7	210.6	117.6	175	164	50	24	34	34
4.5 R	1,710	360.0	205.2	211.1	118.6	165	154	53	27	None.	34
3.5 R	1,720	357.0	204.7	210.6	117.6	173	160	45	22	29	31
Low test gasoline mixtures.											
*	1,710	375.0	213.7	219.8	123.5	178	167	45	26	....	....
25 B	1,710	350.0	199.5	205.2	115.3	174	157	44	26	23	26
20 B	1,700	335.0	189.8	195.2	110.3	170	156	44	26	26	29
30 B	1,710	341.0	194.3	199.8	112.3	178	164	48	26	29	34
Aviation gasoline mixtures.											
15 B	1,700	364.5	206.5	212.4	120.1	176	164	48	27	34	36

* Run on main tank, 5 per cent ortho-toluidine in aviation gasoline. Barometer, 29.09 in. Hg.

Carburetor setting:

Chokes, $1\frac{1}{16}$ inches.
Main jets, 49.
Comp. jets, 52.

RUN NO. 5.

300-horsepower Hispano-Suiza engine—Compression ratio, 5.3:1.

Per cent dope.	Revolutions per minute.	Actual—		Corrected—		Water temperature (°F.).		Carburetor air temperature (°F.).	Spark setting (degrees).		
		Brake load (pounds).	B. H. P.	H. P.	B. M. E. P. (pounds per square inch).	In.	Out		Best power.	Detonation.	Power drop.
Aviation gasoline mixtures with ortho-toluidine. Barometer, 29.29 in. Hg.											
*	1,800	540.5	324.2	332.9	129.3	130	149	54	27	None.	36.5
3	1,810	535.0	322.7	329.6	128.0	132	150	50	31	38.5	36.5
2½	1,820	539.0	327.0	334.1	129.0	130	146	54	27	36.5	33.5
2	1,810	538.0	324.6	331.6	128.8	130	147	57	27	31.0	31.0
1½	1,790	535.0	319.2	326.2	128.0	132	151	59	27	27.0	31.0
Barometer changed to 29.21 in. Hg.											
2	1,810	538.5	325.0	332.9	129.2	132	148	54	27	31.0	31.0
2½	1,800	540.0	324.0	331.8	129.6	129	146	52	27	31.0	31.0
2½	1,810	539.0	325.2	333.1	129.3	134	150	52	27	36.5	33.5
Low test gasoline mixtures with ortho-toluidine.											
*	1,810	527.5	318.3	326.0	126.6	132	150	52	27	31.0	31.0
4½	1,790	529.5	316.0	323.6	127.0	135	151	56	27	24.0	31.0
5½	1,800	530.0	318.0	325.7	127.2	133	151	62	27	36.5	33.5

* Run on main tank, 5 per cent ortho-toluidine in aviation gasoline.

RUN NO. 6.

Single-cylinder Liberty engine—5.4:1 compression ratio—Aviation gasoline mixtures with (R) ortho-toluidine and (X) xylidine, full throttle.

Per cent dope.	Revolutions per minute.	Actual—		Corrected—		Carburetor air temperature (°F.).	Spark setting (degrees).		
		Brake load (pounds).	B. H. P.	B. M. E. P. (pounds per square inch).	I. M. E. P. (pounds per square inch).		Best power.	Detonation.	Power drop.
3.0 X	1,710	92.0	39.33	134.7	168.4	53	28½	None.	42½
2.0 X	1,680	91.5	38.43	133.9	167.4	49	28½	None.	28½
1.5 X	1,720	92.1	39.61	134.8	168.5	48	24½	32	30½
1.25 X	1,690	92.5	39.08	135.4	169.3	47	28½	34	36
1.0 X	1,692	92.5	39.12	135.4	169.3	48	23½	32	32
1.75 X	1,690	92.5	39.08	135.4	169.3	48	24½	34	32
2.0 X	1,690	92.75	39.18	135.8	169.8	47	28½	32	32
Throttle set to give 134 pounds per square inch indicated mean effective pressure on aviation gasoline.									
2.0 X	1,692	76.10	32.19	111.4	139.3	50	32	None.	36
1.75 X	1,760	75.75	33.34	110.9	138.6	56	36	None.	39
1.50 X	1,690	75.10	31.74	109.9	137.4	56	32	None.	39
1.50 R	1,690	75.75	32.00	110.9	138.6	52	32	36	36
1.75 R	1,690	75.25	31.80	110.1	137.6	52	36	42	42

Barometer, 29.27 in. Hg.

RUN NO. 7.

Single-cylinder Liberty engine—5.4:1 compression ratio—Throttle set to give 134 pounds per square inch indicated mean effective pressure on aviation gasoline—Low test gasoline mixtures with (X) xylidine and (R) ortho-toluidine.

Per cent dope.	Revolutions per minute.	Actual—		Corrected—		Carburetor air temperature (°F.).	Spark setting (degrees).		
		Brake load (pounds).	B. H. P.	B. M. E. P. (pounds per square inch).	I. M. E. P. (pounds per square inch).		Best power.	Detonation.	Power drop.
Barometer 29.35 in. Hg.									
4.0 X	1,700	70.00	29.75	102.2	127.7	83	24	24	26½
5.0 X	1,710	75.12	32.10	109.7	137.1	75	24½	32	32
5.5 X	1,740	75.37	32.78	110.0	137.5	61	24	32	32
6.0 X	1,660	76.50	31.75	111.7	139.6	62	24	32	32
Barometer changed to 29.37 in. Hg.									
7.0 X	1,656	78.25	32.40	114.1	142.6	62	24	36	32
7.5 X	1,690	77.00	32.53	112.3	140.4	63	32	42	39
1.0 * 7.5 R	1,704	76.62	32.64	111.8	139.7	74	26½	39	34
2.0 * 8.0 R	1,700	77.25	32.83	112.7	140.9	77	30½	None.	36
2.0 * 7.0 R	1,717	77.50	33.26	113.1	141.4	73	27½	36	36

* Per cent benzol added to obtain miscibility.

RUN NO. 8.

Single-cylinder Liberty engine—5.4:1 compression ratio—Throttle set to give 134 pounds per square inch indicated mean effective pressure on aviation gasoline—Aviation and low-test gasoline mixtures with benzol.

Per cent benzol.	Revolutions per minute.	Actual—		Corrected—		Carburetor air temperature (°F.).	Spark setting (degrees).		
		Brake load (pounds).	B. H. P.	B. M. E. P. (pounds per square inch).	I. M. E. P. (pounds per square inch).		Best power.	Detonation.	Power drop.
Aviation gasoline mixtures. Barometer, 29.42 in. Hg.									
12½	1,680	75.0	31.50	109.2	136.5	74	23½	30½	30½
15	1,700	75.5	32.09	109.9	137.4	76	26½	31	31
17½	1,680	75.5	31.71	109.9	137.4	77	26½	37	30½
20	1,690	76.0	32.11	110.7	138.4	76	26½	41½	30½
25	1,710	78.75	33.67	114.7	143.4	74	30½	[1] 42	32
Low test gasoline mixtures. Barometer, 29.36 in. Hg.									
30	1,700	74.75	31.77	109.1	136.4	66	24	30½	30½
35	1,690	74.25	31.36	108.3	135.4	70	24	30½	30½
40	1,710	74.25	31.74	108.3	135.4	72	24	36	30½
45	1,710	73.12	31.26	106.7	133.4	79	24	41½	30½

[1] None.

RUN NO. 9.

Single-cylinder Liberty engine—5.4:1 compression ratio—Throttle set to give 134 pounds per square inch indicated mean effective pressure on aviation gasoline—Aviation and low-test gasoline mixtures with General Motors Anti-Knock No. 1.

Per cent dope.	Revolutions per minute.	Actual— Brake load (pounds).	Actual— B. H. P.	Corrected— B. M. E. P. (pounds per square inch).	Corrected— I. M. E. P. (pounds per square inch).	Carburetor air temperature (°F.).	Spark setting (advance). Best power.	Spark setting (advance). Detonation.	Spark setting (advance). Power drop.
Aviation gasoline mixtures. Barometer, 29.27 in. Hg.									
2.0	1,700	75.75	32.20	110.9	138.7	60	39	39	42½
2.5	1,680	76.50	32.13	112.0	140.0	62	36	....	([1])
Barometer changed to 29.20 in. Hg.									
2.5	1,710	77.00	32.92	113.0	141.3	65	33½	41½	41
3.0	1,700	76.50	32.51	112.3	140.4	64	33	[3] 42½	41
3.5	1,690	75.50	31.90	110.8	138.5	65	34	[2] 42½	41
3.0	1,700	76.12	32.35	111.7	139.6	66	34	42½	38½
2.5	1,700	76.12	32.35	111.7	139.6	67	41½	41½	38
Low-test gasoline mixtures.									
10	1,710	76.12	32.54	111.7	139.6	68	25½	41	38½
11	1,700	75.00	31.88	110.1	137.6	69	25½	[3] 42½	38
10.5	1,710	75.75	32.38	111.2	139.0	69	29½	38½	38½
10	1,700	76.37	32.45	112.1	140.1	68	34	41½	38½
10.5	1,690	76.50	32.31	112.3	140.4	68	34	42½	38½

[1] Cam case cover broke. [2] Some. [3] None.

RUN NO. 10.

Single-cylinder Liberty engine—6.7:1 Compression ratio—Throttle set to give 146 pounds per square inch indicated mean effective pressure with 50 per cent benzol mixture [1]—Aviation and low-test gasoline mixtures with General Motors Anti-Knock No. 1.

Per cent dope.	Revolutions per minute.	Actual— Brake load (pounds).	Actual— B. H. P.	Corrected— B. M. E. P. (pounds per square inch).	Corrected— I. M. E. P. (pounds per square inch).	Carburetor air temperature (°F.).	Spark setting (degrees). Best power.	Spark setting (degrees). Detonation.	Spark setting (degrees). Power drop.
Aviation gasoline mixtures.									
7	1,700	78.50	33.36	117.0	146.3	70	29½	28½	34
7½	1,690	81.00	34.22	120.7	150.9	71	29½	29½	34
8	1,700	81.87	34.80	122.0	152.5	71	29½	29½	34
9	1,710	84.00	35.91	125.2	156.5	64	29½	34	34
10	1,690	85.12	35.96	126.8	158.5	65	30½	38	34
Low-test gasoline mixtures.									
15	1,700	82.75	35.17	123.3	154.6	62	30½	26½	34
17½	1,710	86.25	36.87	128.5	160.6	62	30½	40½	38
16	1,690	85.25	36.02	127.0	158.8	64	30½	32	34

Barometer, 26.75 in. Hg.
[1] Multicylinder engine tests on which throttle settings for indicated mean effective pressures are based were run with 50 per cent benzol mixture as fuel.

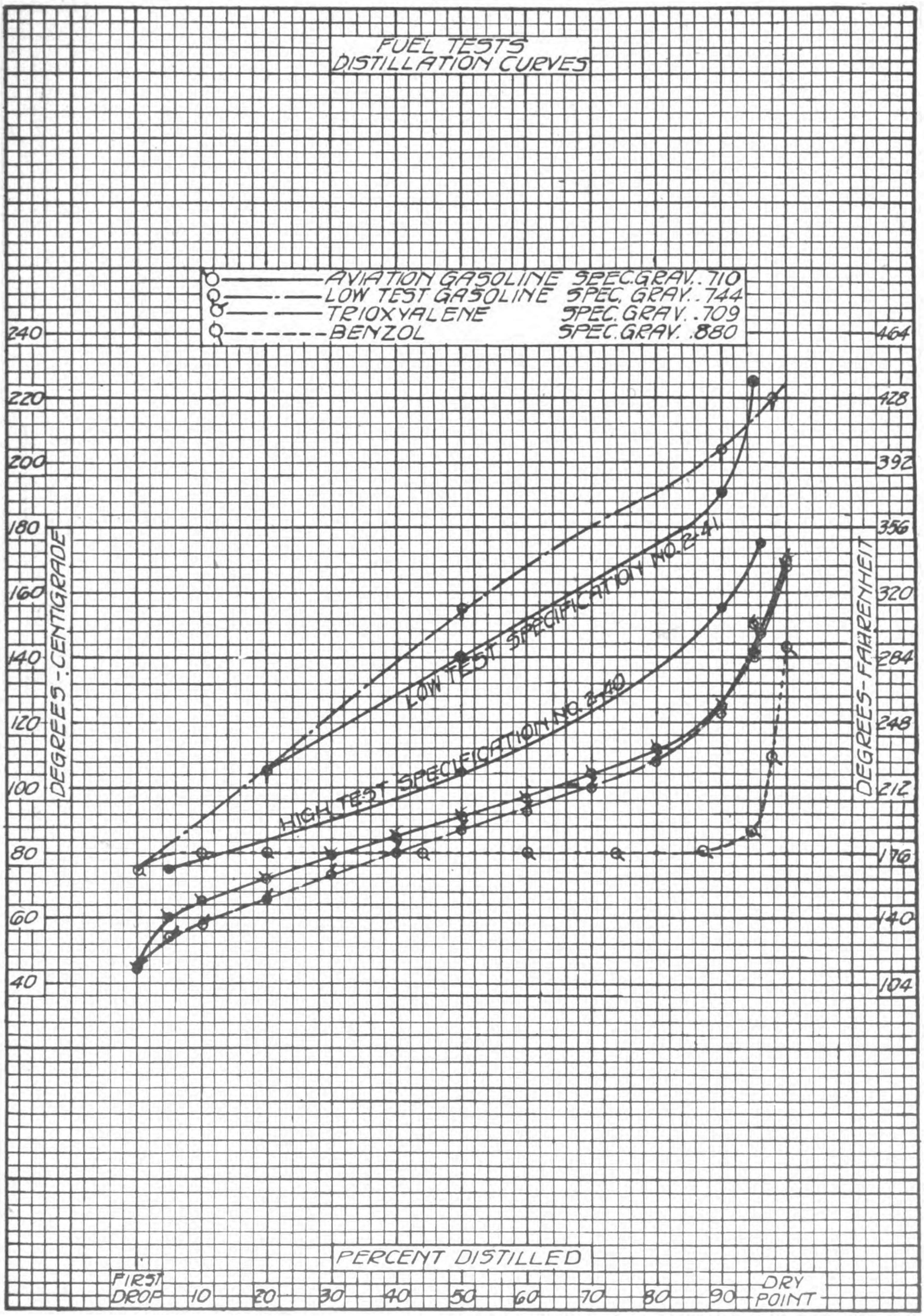
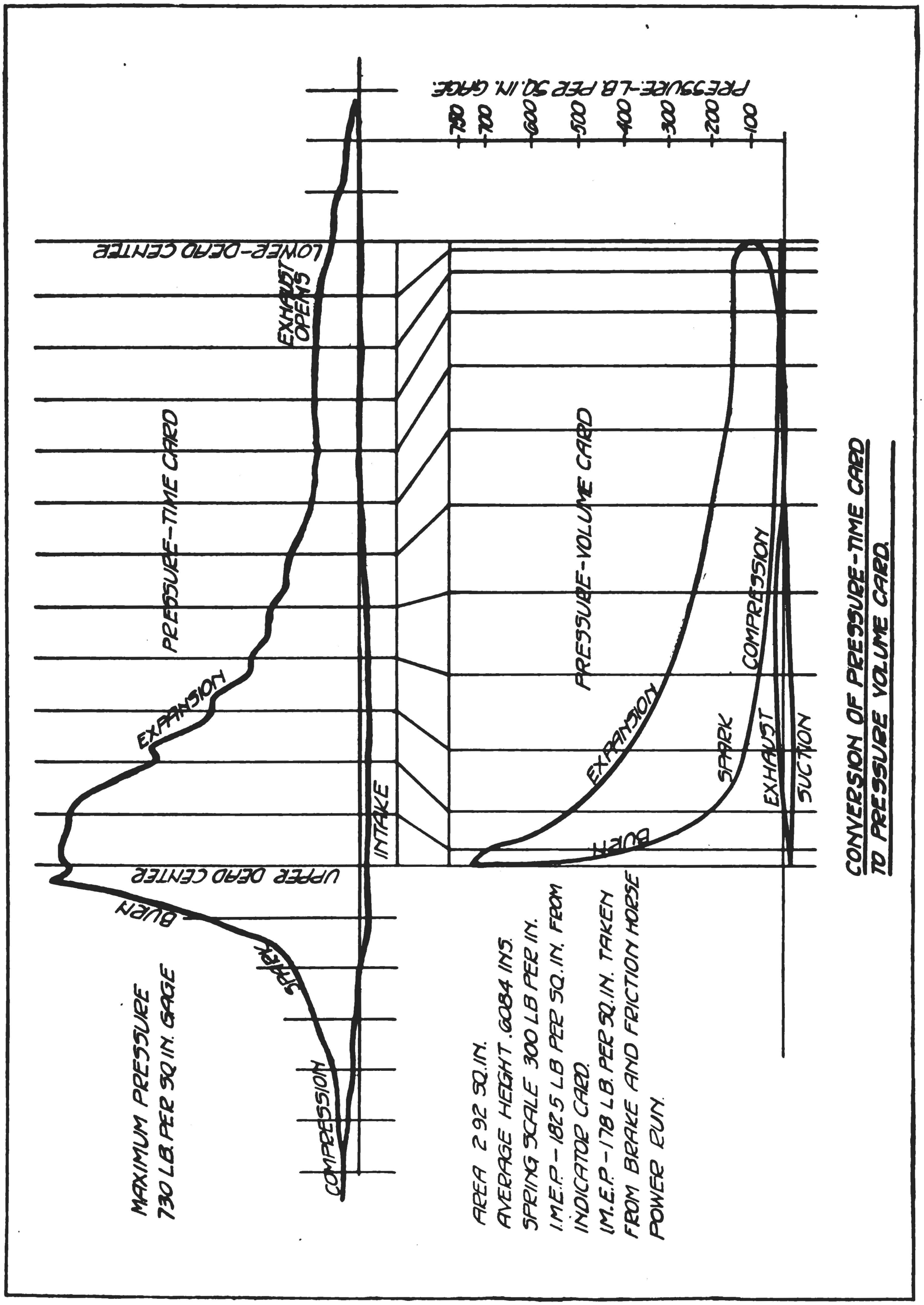

FUEL TESTS
DISTILLATION CURVES
AVIATION GASOLINE SPEC. GRAV. .710
LOW TEST GASOLINE SPEC. GRAV. .744
TRIOXYALENE SPEC. GRAV. .709
BENZOL SPEC. GRAV. .880
LOW TEST SPECIFICATION NO. 2-41
HIGH TEST SPECIFICATION NO. 2-40
DEGREES - CENTIGRADE
DEGREES - FAHRENHEIT
240
220
200
180
160
140
120
100
80
60
40
464
428
392
356
320
284
248
212
176
140
104
PERCENT DISTILLED
FIRST DROP
10
20
30
40
50
60
70
80
90
DRY POINT

FIG. 1.



CONVERSION OF PRESSURE-TIME CARD
TO PRESSURE VOLUME CARD.

FIG. 2.

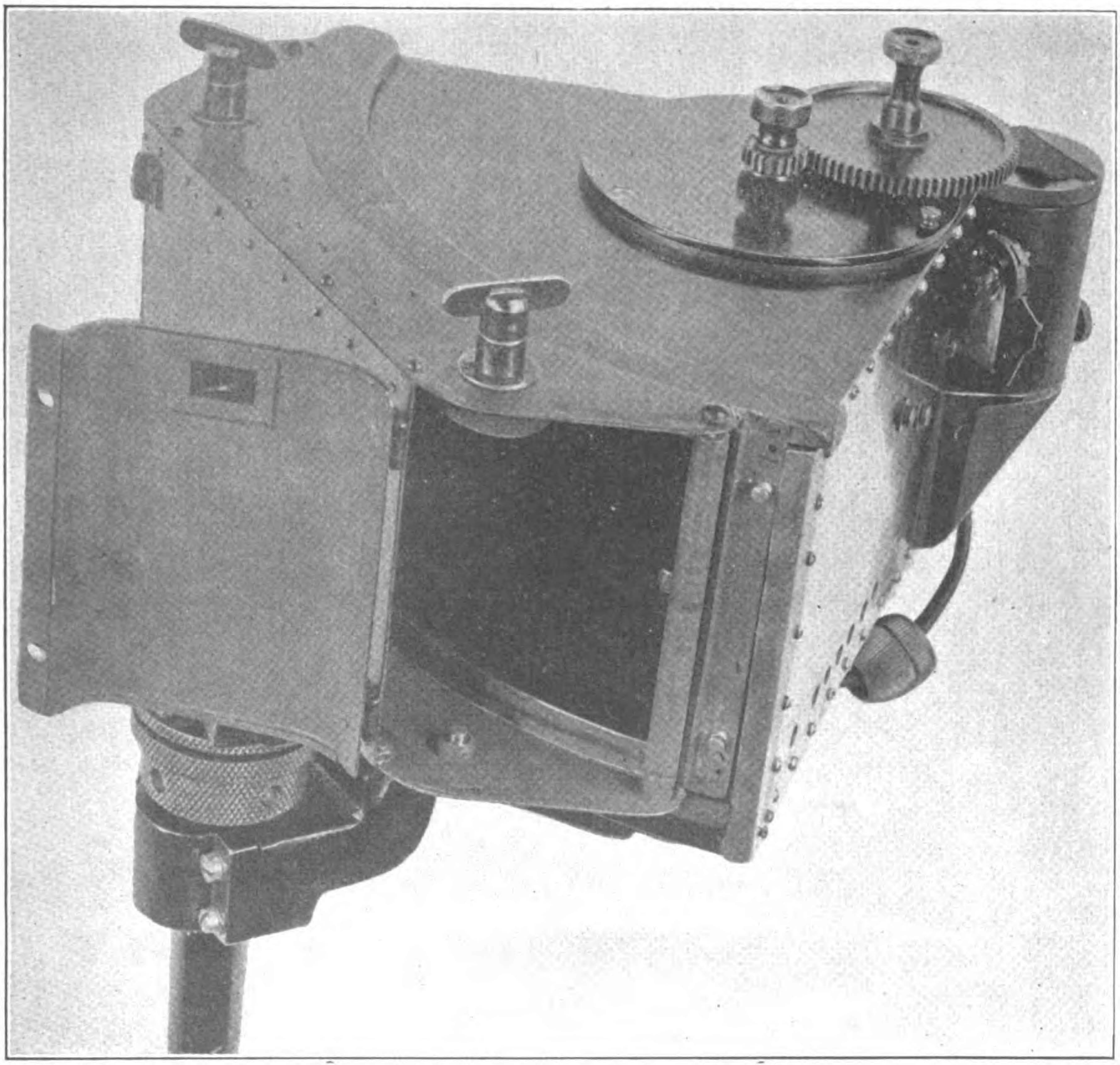


FIG. 3.—Midgley indicator with film adapter.

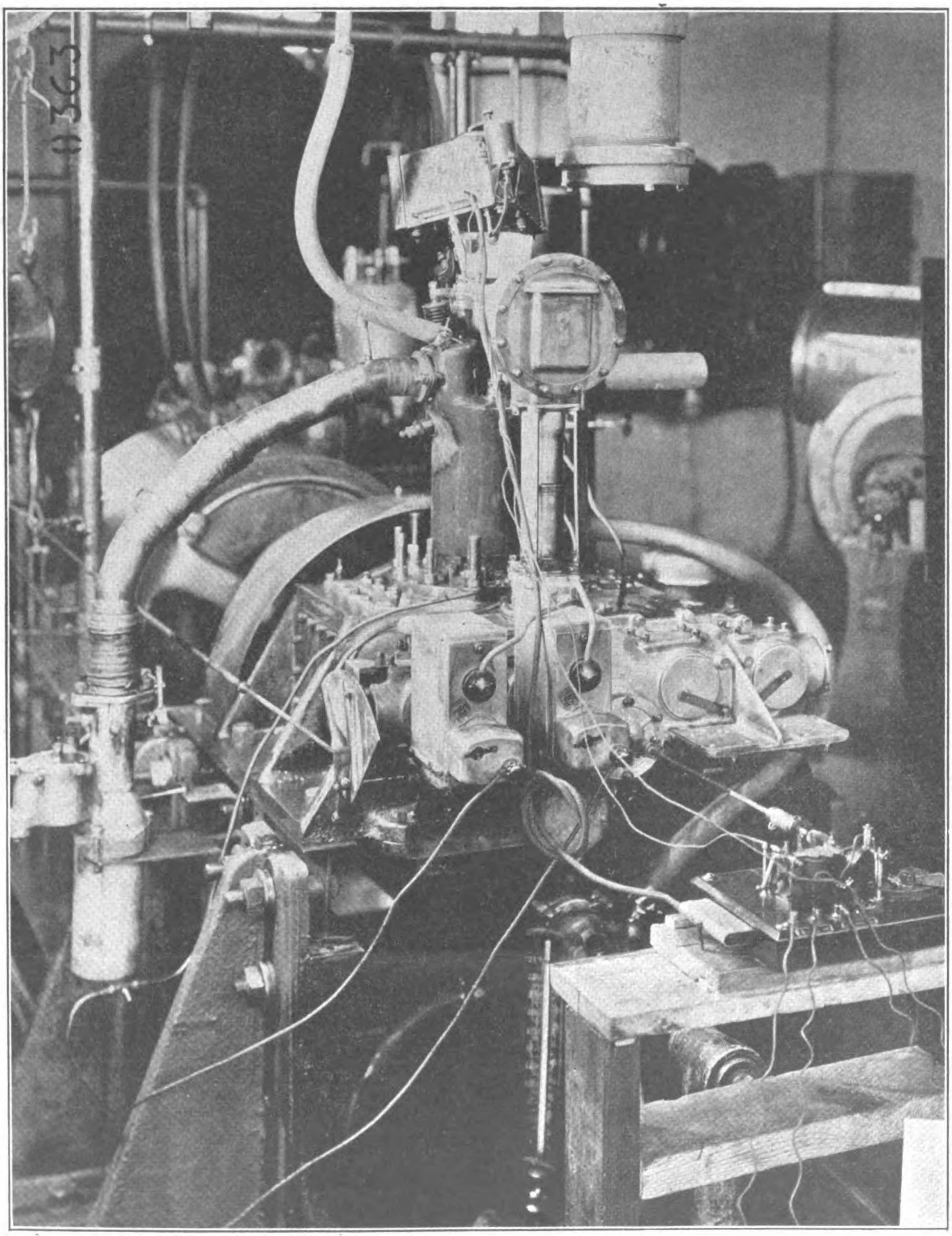


FIG. 4.—Midgley indicator set up on single cylinder Liberty engine.

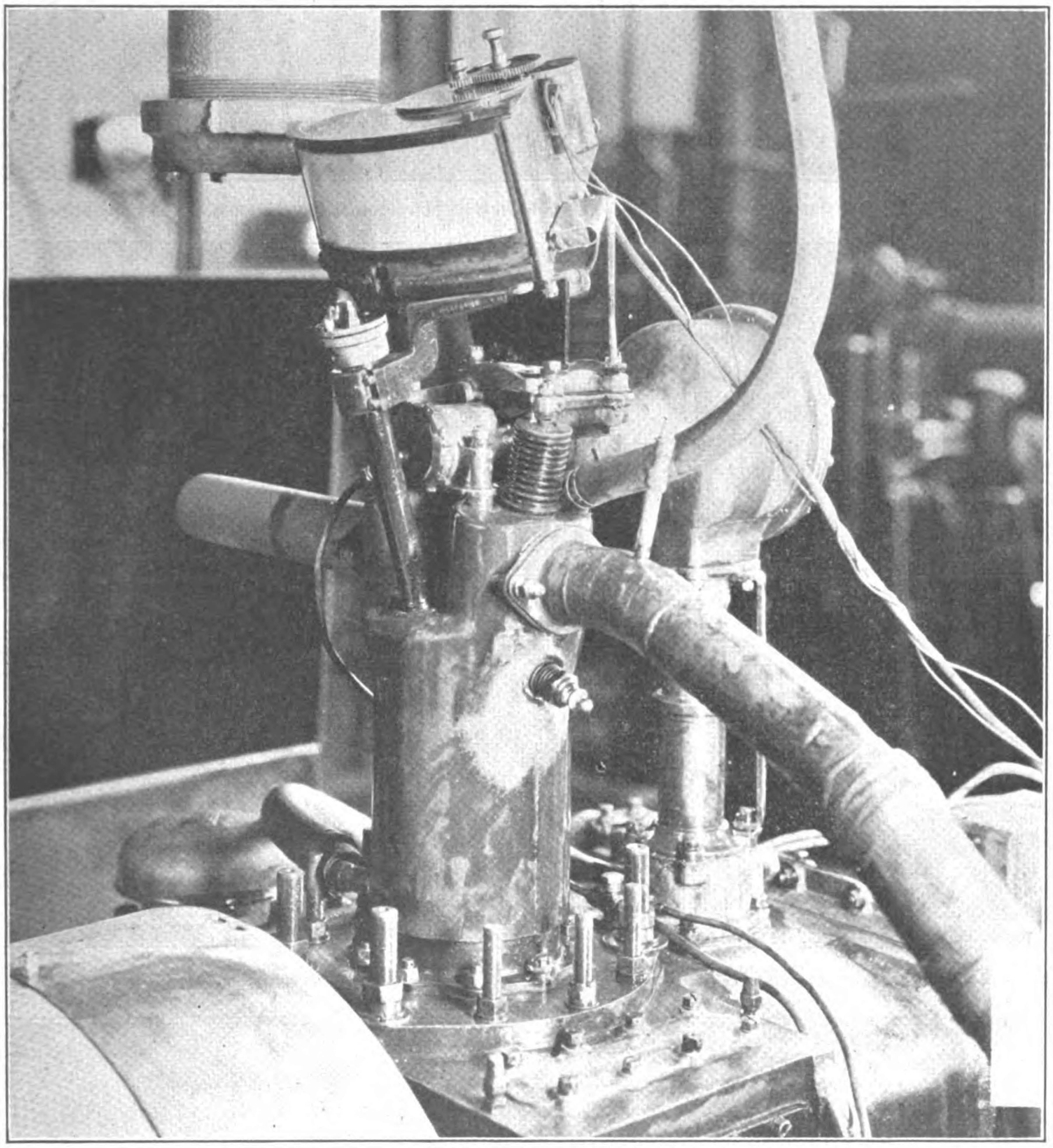


FIG. 5.—Midgley indicator set up on a single cylinder Liberty engine, with ground glass in place.

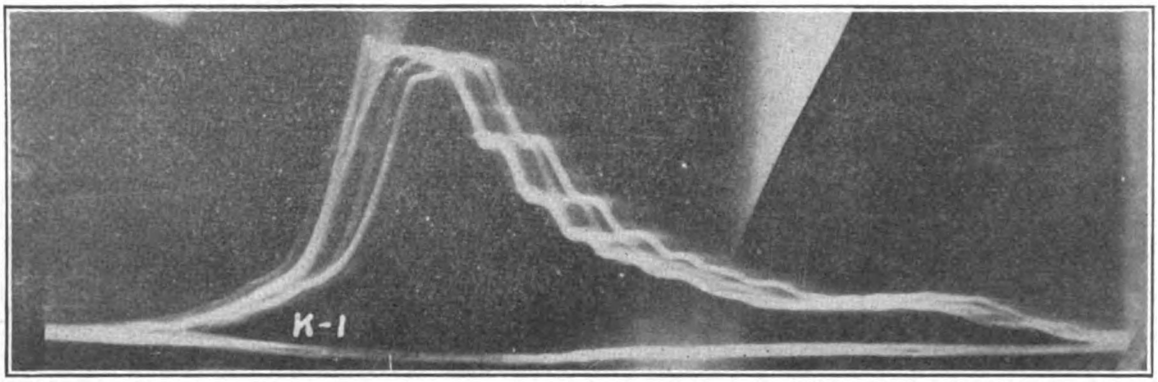


FIG. 6.—K-1.—Benzol. B. M. E. P. 143 pounds per square inch. I. M. E. P. 178.8 pounds per square inch. Spark advance 35°.

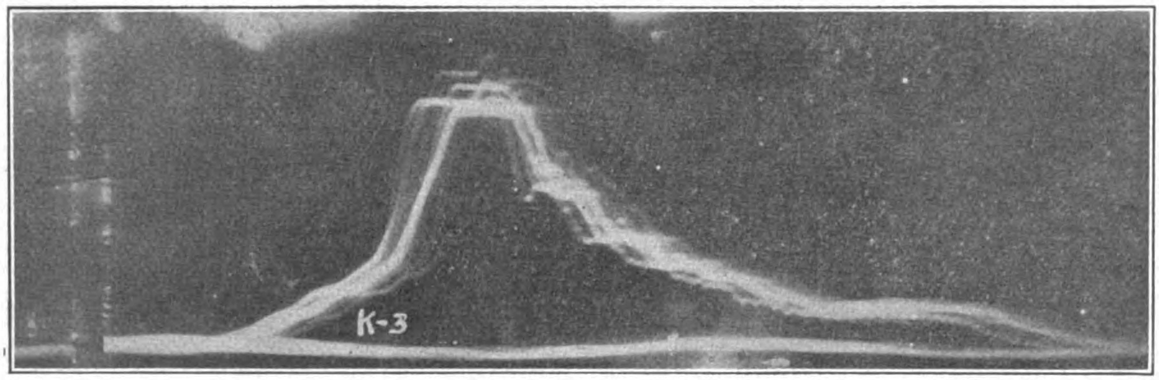


FIG. 7.—K-3.—Aviation gasoline with 9 per cent General Motors Anti-Knock No. 1. B. M. E. P. 138.6 pounds per square inch. Spark advance 30½°.

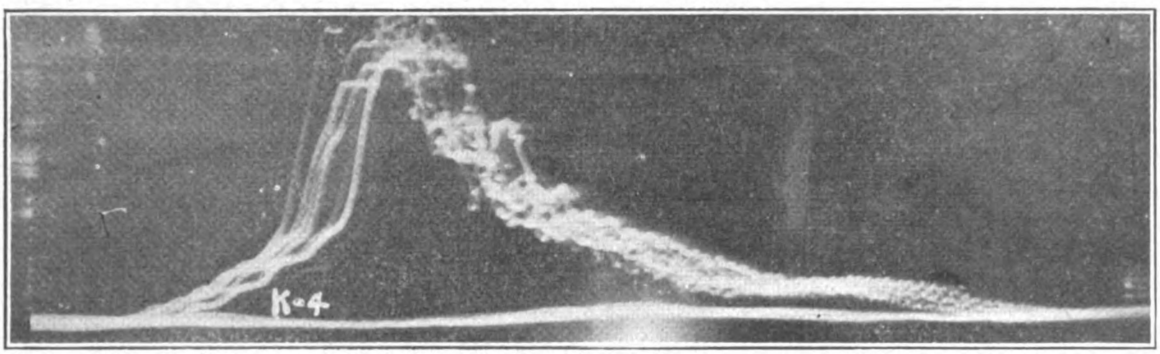


FIG. 8.—K-4.—Aviation gasoline with 7½ per cent General Motors Anti-Knock No. 1. B. M. E. P. 135.7 pounds per square inch. Spark advance 27½°.

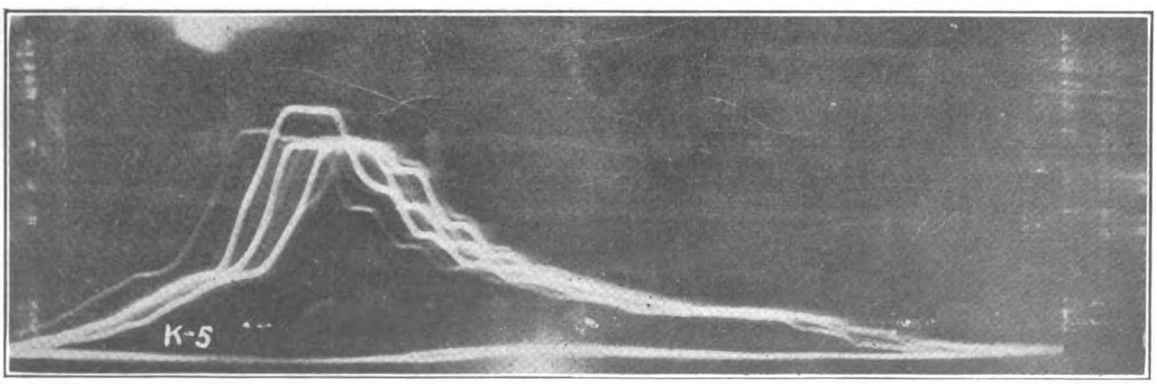


FIG. 9.—K-5.—Aviation gasoline with 7½ per cent General Motors Anti-Knock No. 1. B. M. E. P. 138.6 pounds per square inch. Spark advance 22°.

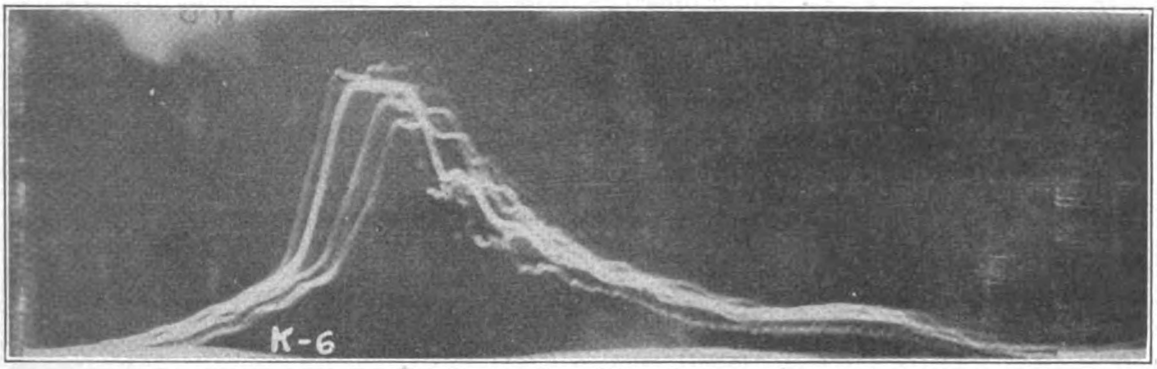


Fig. 10.—K-6.—Aviation gasoline with 10½ per cent General Motors Anti-Knock No. 1. B. M. E. P. 143 pounds per square inch. Spark advance 28½°.

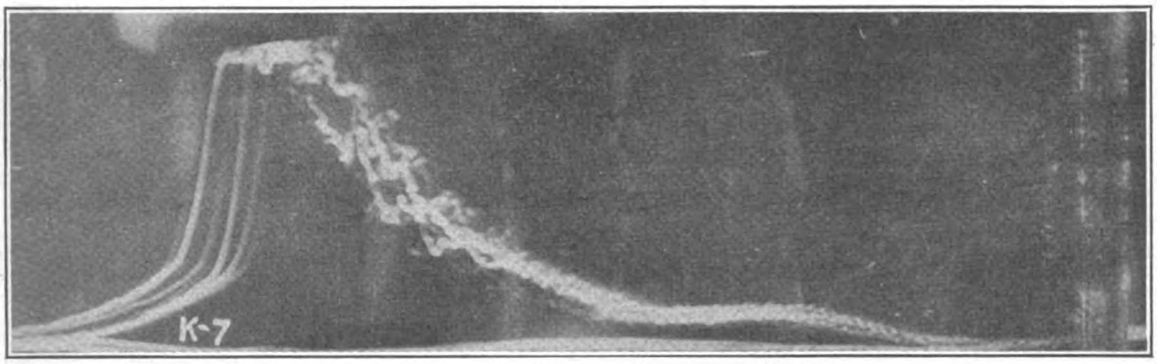


Fig. 11.—K-7.—Aviation gasoline with 10½ per cent General Motors Anti-Knock No. 1. B. M. E. P. 141.6 pounds per square inch. Spark advance 36°.

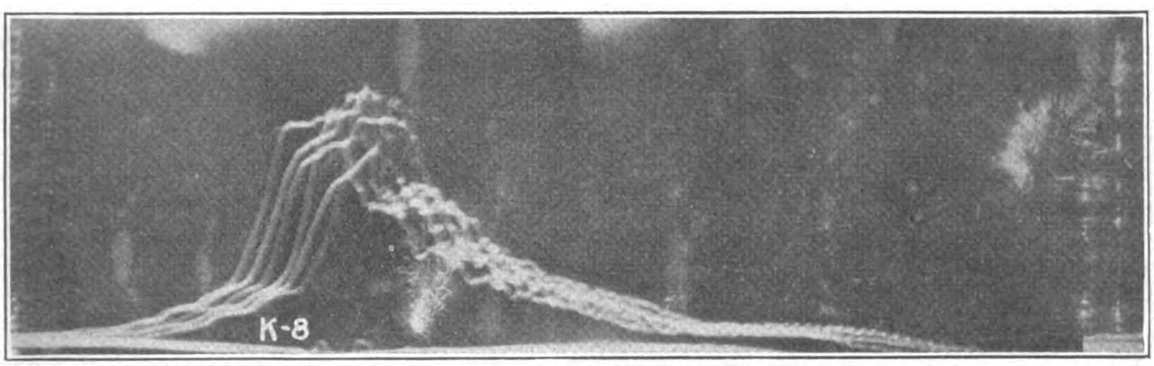


Fig. 12.—K-8.—Aviation gasoline straight. B. M. E. P. 89.95 pounds per square inch. Spark advance 26½°.

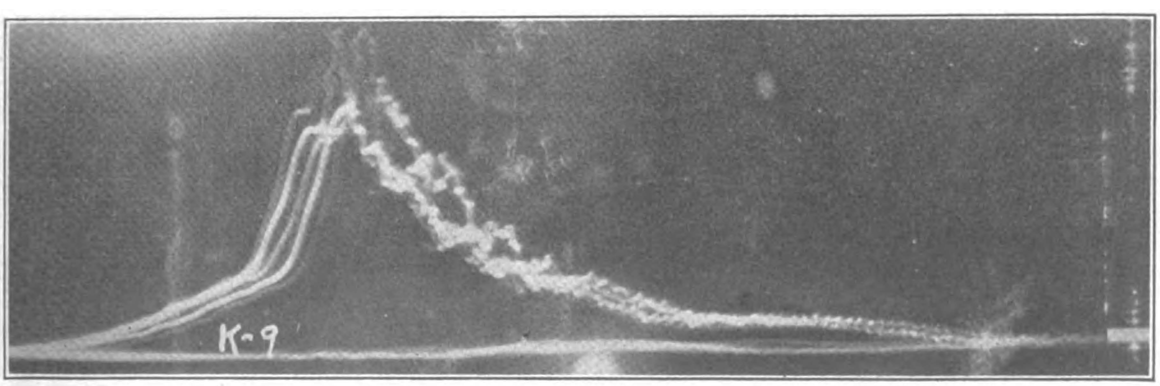


Fig. 13.—K-9.—Trioxyalene (80 per cent low test gas and 20 per cent ether). B. M. E. P. 107.6 pounds per square inch. Spark advance 25°.

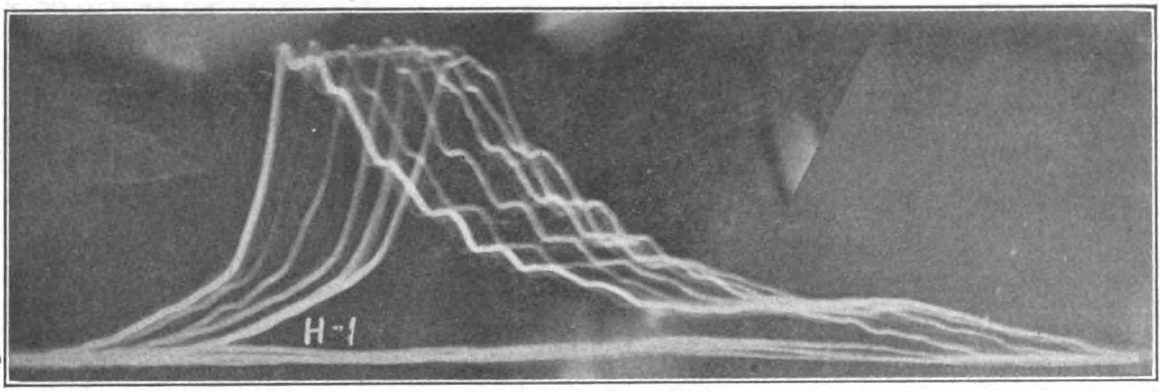


FIG. 14.—H-1.—Aviation gasoline with 10 per cent General Motors Anti-Knock No. 1. Full throttle. B. M. E. P. 145.1 pounds per square inch.

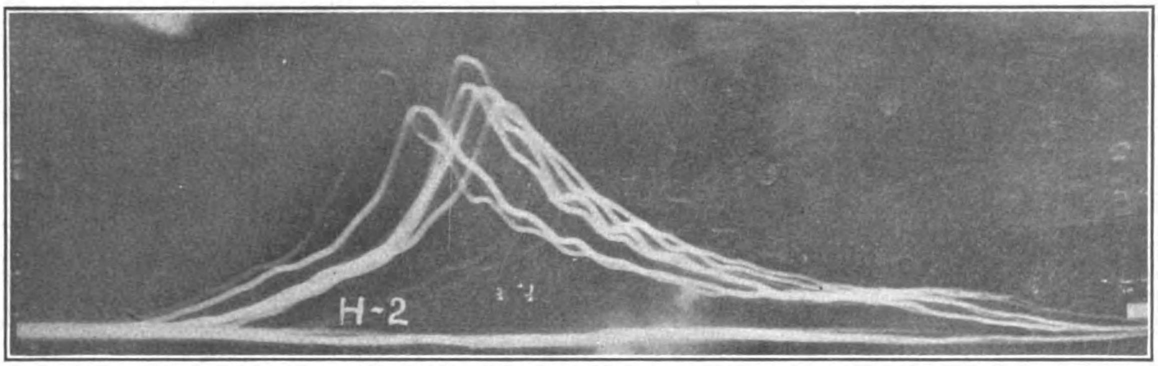


FIG. 15.—H-2.—Aviation gasoline with 7 per cent General Motors Anti-Knock No. 1. B. M. E. P. 133.2 pounds per square inch. Throttled to eliminate detonation.

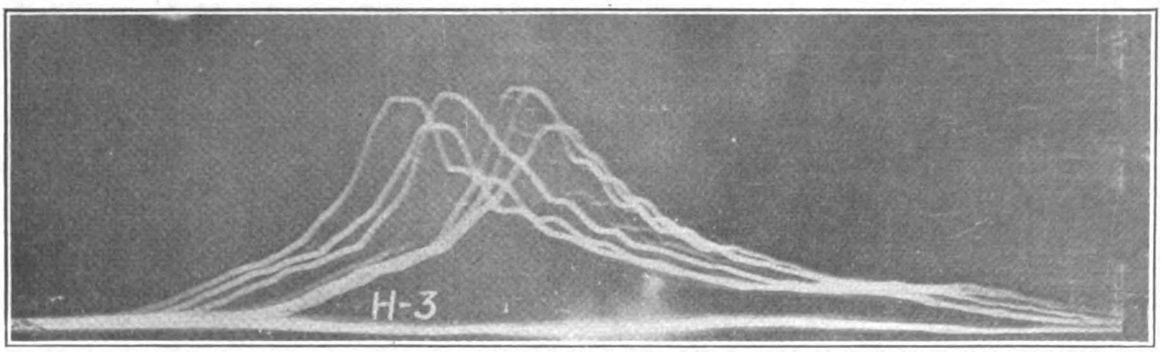


FIG. 16.—H-3.—Aviation gasoline with 5 per cent General Motors Anti-Knock No. 1. B. M. E. P. 127.3 pounds per square inch. Throttled to eliminate detonation.

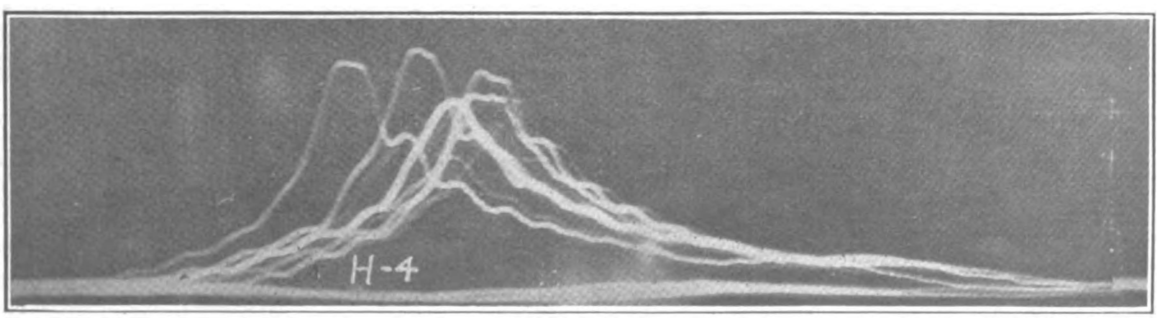


FIG. 17.—H-4.—Aviation gasoline straight. B. M. E. P. 103.6 pounds per square inch. Throttled to eliminate detonation.

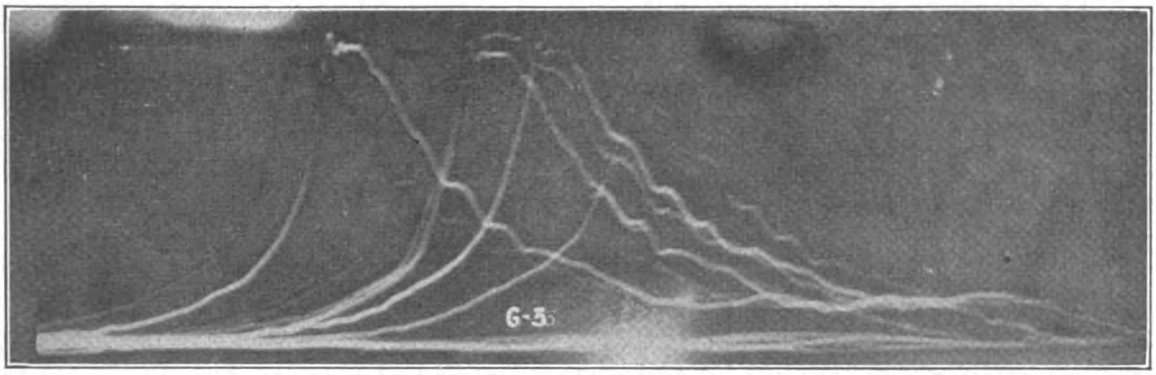


FIG. 18.—G-3.—Low-test gasoline with 18½ per cent of General Motors Anti-Knock No. 1. B. M. E. P. 144.7 pounds per square inch.

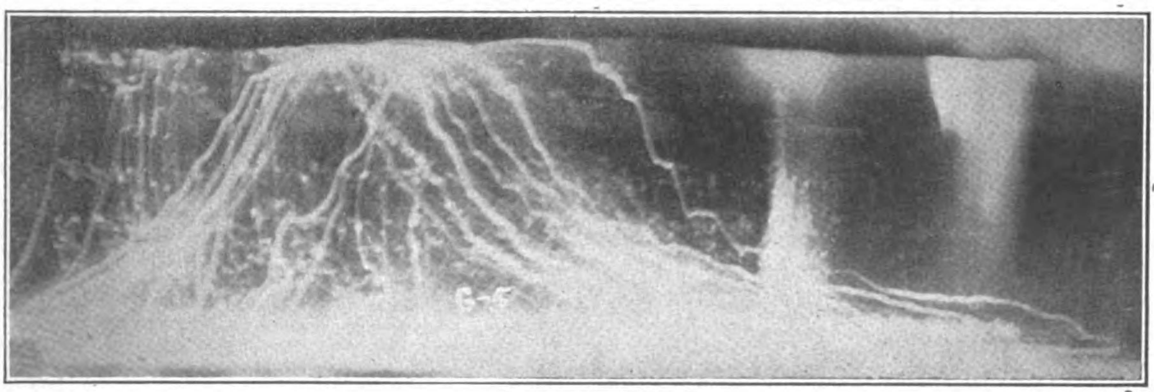


FIG. 19.—G-5.—Preignition. Aviation gasoline.

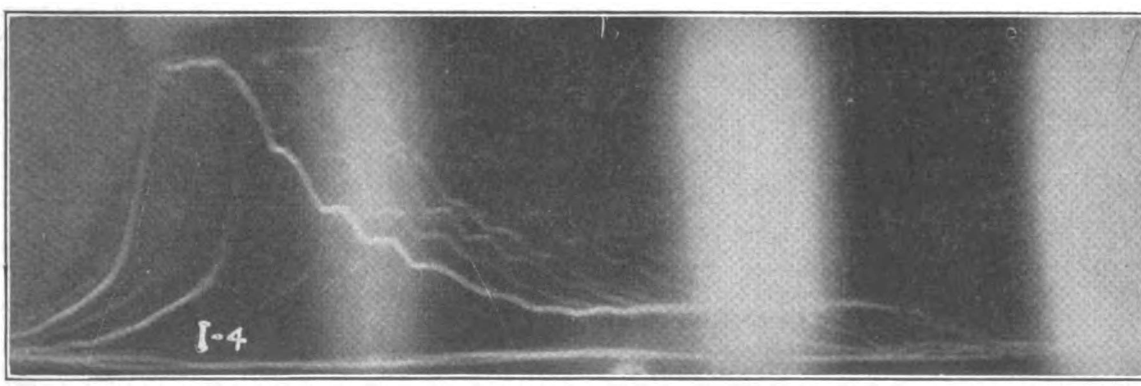


FIG. 20.—I-4.—Benzol. Two spark plugs, one under exhaust valve and one in top of head. B. M. E. P. 146 pounds per square inch. Spark advance 36°.

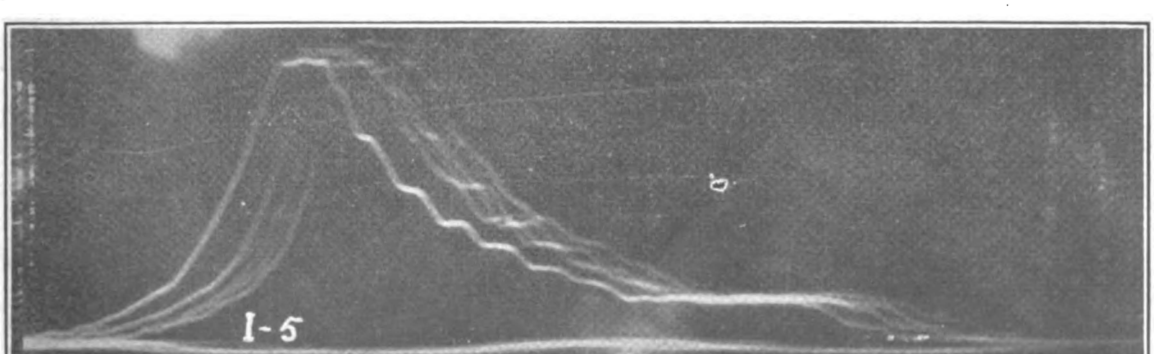


FIG. 21.—I-5.—Benzol. One spark plug only, under exhaust valve. B. M. E. P. 146 pounds per square inch. Spark advance 40°.

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